STATISTICS ON MINE BLASTING AND BLASTING SIGNALS IN DIFFERENT REGIONS: PRELIMINARY RESULTS FROM RUSSIA AND KAZAKHSTAN

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ABSTRACT

We have recently begun a project to document the numbers of mine blasts that will be detected teleseismically, and at regional distances, by seismograph networks used to monitor compliance with a Comprehensive Test Ban Treaty. We plan to study blasting in the United States, in countries of the former Soviet Union, and in Australia, Canada, China, and Korea. Knowledge of mine blast statistics is needed in order to plan efforts in discrimination, recognizing that in general it is more difficult to tell the difference, from seismic data, between underground nuclear and chemical explosions, than between underground nuclear explosions and earthquakes. If the number of large mine blast signals is large, the effort to analyse such signals could swamp discrimination programs.

So far we have acquired and analysed mine blast data from eight different areas of the former Soviet Union. We have established as a total for all these regions that only on the order of 30 blasting events per year have K (energy class) value of 9 or greater – corresponding to m_b around 3.35 or greater. Also, the slope of the frequency-magnitude relation is much steeper for mine blasting signals, than for earthquakes (the b-value is greater than 2 for blasting, and around unity for earthquakes). This latter result is good from the perspective of concern over very large blasts – because it implies there are very few such events. It also indicates that the number of blast signals rises very rapidly as one considers events with magnitude below about m_b 3.25.

Keywords: mine blasting, seismic discrimination, CTBT monitoring

OBJECTIVE

Our goal is to document the rates of occurrence of chemical explosions of different sizes, in as many mining regions as possible, but with a focus on the observability of blasting signals originating in the former Soviet Union, Australia, Canada, possibly China, Korea, and the U.S.

The size of a chemical explosion is expressed commonly in terms of charge size. But we shall be more interested in size expressed in terms of seismic magnitude, whether local, regional, or teleseismic, since our concern is with the observability of blasting activity. We shall be particularly interested in estimating the numbers of chemical explosions that occur in different regions and that are detected teleseismically with $m_b > 3$. Underlying our work, is the fact that mine blast signals are less easily discriminated from nuclear explosion signals, than are earthquake signals, so mine blast signals may require more sophisticated analysis in programs of CTBT verification. Therefore, large numbers of detectable mining blasts would represent a problem for those who must routinely identify the nature of seismic sources (earthquake, mining blast, underground nuclear explosion). Our project will help estimate the extent of this problem, by making surveys of the observability of mine blast signals of various sizes.

RESEARCH ACCOMPLISHED

Prior to starting this project in June 1995, we had preliminary indications for the U.S. that, in practice, only around 10 to 30 mine blasts appeared to be detectable teleseismically with $m_b > 3$. This number was surprisingly low, since, using magnitude-yield relationships for contained single-fired tamped explosions, one would expect from knowledge of the amounts of chemical explosives used, that thousands of U.S. blasts would be teleseismically detectable each year by sensitive arrays (Richards *et al*, 1992; Richards, 1995). For the first six months of GSETT-3, it has turned out (Eric Bergman, personal communication) that about one U.S. blast each week has been reported in the Reviewed Event Bulletin – and that such events are detected and located mainly on the basis of regional, not teleseismic, signals. The REB therefore confirms our preliminary indications for the U.S., on the low numbers of observable blast events.

The reason for the low numbers in the case of the U.S., is that it is inappropriate to apply magnitude-yield relationships for contained single-fired tamped explosions to the problem of estimating the seismic magnitude of a commercial blast of known charge size. Commercial blasts are inefficient at exciting impulsive body-wave signals, compared to tamped single-fired explosions, because virtually all mine blasts in the U.S. are ripple fired. Commercial blasts are also poorly coupled (another way of saying they are inefficient at exciting signals), because the purpose of commercial blasting is almost always to break rock into fragments of predetermined size, and, to this end, commercial blasts are usually not fully contained.

To carry out our surveys for different mining regions around the world, we have begun with acquisition of six different types of information, as follows:

- coordinates of active quarries and mines, in the different regions we shall study;
- lists of times at which representative blasts, and large blasts, occurred;

- information on total charge size, and, if possible, of blasting patterns (numbers of holes, charge size and timing of delays);
- regional magnitudes for mining blasts;
- information on the teleseismic observability of mining blasts; and
- pertinent seismograms, for our own analysis.

We are particularly interested in blasts that are detected teleseismically with $m_b > 3$, and/or are detected by regional signals out to distances of 1000 km or more, since such blasts may well be reported routinely by global networks organized for CTBT monitoring. As part of our analysis, we have an interest in comparing various regional magnitude scales and duration magnitude scales, preferably against the teleseismic (m_b) scale. Comparison of magnitudes against charge size is also of interest, though substantial scatter is to be expected. We shall also study the relation between the regional Russian K scale and teleseismic m_b for underground nuclear explosions, mine blasts, and earthquakes in different regions.

Our contract began in June 1995, and to date our preliminary results are for some of the countries of the former Soviet Union. In the remainder of this section, we first list the types of data we have acquired for several different regions; and then we give four Figures that summarize the main features of blasting that we have been able to document so far in this project.

Kazakhstan: southeastern region (Northern Tien-Shan, 42–46°N, 75–80°E)

We have a list of blast dates and times, and charge sizes, for several tens of events in 1994. For several of these events, we have been able to find waveform data at the Kurchatov 21-element array, operated since the summer of 1994 by Lamont (under IRIS's Joint Seismic Program) on the former Semipalatinsk Test Site.

We have a longer blast list, handwritten for 5399 events, for the period 1979 – 1994, used to prepare parts of Figures 1 and 3 (discussed further, below).

We also have all relevant information (date, time, K value, duration magnitude, charge size, and quarry locations) for more than 120 blasts during 1972 – 1976 in the area around the capital city of Almaty.

Kazakhstan: south central region around Dzhambul (41.5–44°N, 68–74°E)

We have a list of about 2130 blasts with known date (during June 1988 to December 1991), time of day, and signal strength.

Russia: Lake Baikal region

We have a map and a listing of quarry/mine locations.

Russia: Caucasus region around Anapa (N.W. Caucasus, 44.1–45.7°N, 36.1–38.3°E).
Also the Caucasus region to the south around Kislovodsk

We have quarry/mine locations, catalogs of blasts for several years, and a catalog of

earthquakes (the basis for parts of Figures 3 and 4, discussed below). In the southern Caucasus around Kislovodsk, Lamont operated a regional network during 1991 – 1992 under IRIS's Joint Seismic Program, and the resulting waveform data have been worked up (for example in Vigen Aharonian's 1994 master's paper at Lamont/Columbia University) for numerous small blasts and earthquakes.

Russia: Kuzbass region (southeast of Novosibirsk)

We have a map and a listing of quarry/mine locations. We have identified waveforms for several large events from this region, recorded at a distance of approximately 700 km with high signal-to-noise, at the Kurchatov array operated by Lamont.

Russia: Central Urals

We have a list of quarry/mine names, their location, and distance from the IRIS/GSN/GSETT-3 station at Arti (ARU) in the Urals.

Russia: Far East region ("Primorye", 43.5–56°N, 123.5–138.5°E)

We have a map and a listing of quarry/mine locations, and lists of blast times and blast signal strength.

Ukraine

We have the location of 24 major quarries and mines active in the years 1986 – 1990, and 23 examples of blasts of known latitude, longitude, origin time, and total charge size.

Complete details on the above data, and additional data, will be supplied in future technical reports. In this paper there is space to give only a brief account of two aspects of our newly acquired data. Thus, we have examined:

(1) the distribution of the sizes of seismic signals resulting from blasting, and have compared this distribution to the results for earthquakes in the same region, paying particular attention to the size of the largest blasting events (largest, in terms of seismic signal strength); and

(2) the time distribution (time-of-day) of blasting signals.

Russian and other CIS countries routinely report the strength of seismic sources using the K value, which was designed originally to be an estimate of the logarithm of the total energy, in joules, of radiated seismic waves. The relationship between K value and values of seismic magnitude, on scales commonly used by western seismologists, will be examined at a later stage in our project. Sufficient here to say, that the approximate relationship is

$$K = 9 + 2.32 * [m_b - (3.35 \pm 0.25)].$$

It follows that the K value of blasts of a size likely to be of interest in the context of CTBT monitoring, is around 9 and greater. In some cases there may be interest in blasts with K somewhat less than 9.

It is clear from Table 1 that blasting activity in Kazakhstan is currently much reduced from levels reached during Soviet era. We believe this reduction is likely also to have occurred in Russia and Ukraine. Much of our data comes from the years of greater activity, prior to 1992.

Table 1. Annual numbers of quarry blasts in southeastern Kazakhstan during 1985 - 1994.

		Ranges of K - values		
Year	Total	8.5-8.9	9.0-9.4	>9.4
1985	405			4
1986	371			4
1987	431			5
1988	551	14	9	2
1989	461	21	3	1
1990	489	10	2	2
1991	476	8	2	1
1992	324	2	0	1
1993	136	1	0	0
1994	89	1	0	0

Figure 1 shows the numbers of events (blasts, and earthquakes), in each unit of energy class K, for more than 5000 blasts in a region of southeast Kazakhstan that includes the capital city, Almaty. This display is similar to a typical magnitude-frequency relation, plotted with an incremental rather than a cumulative frequency. Note from the straight-line fit to the earthquake data, that the detection capability of the network used to prepare this Figure is good down to at least $K = 7$. The blast data do not follow a straight line at lower values of K. The fall-off of blasts with signal strength above $K = 8$ is much faster than the fall-off for earthquakes. There are very few blasts events with $K \geq 9$.

Figure 2 shows the numbers of blasting events at four specific mines/quarries in the same region covered in Figure 1, and again we see the rapid fall-off of events with seismic energy class $K \geq 8$, and the paucity of events with $K \geq 9$. These two features are found for all regions of the former Soviet Union for which we have so far acquired data. Whereas the *b*-value in the usual magnitude-frequency relation is about unity for earthquakes, the *b*-value for blasting is greater than 2 in all the regions we have studied so far.

Figure 3 gives the numbers of events per hour-of-day, using GMT, for four different mining areas. The Figure shows that blasting activity is concentrated at certain times, namely during the hours at the end of the regular working day. This feature of blast activity is interesting, in view of the similar type of plot shown in Figure 4, which is supposedly the numbers of earthquakes per hour-of-day, using GMT, for the Caucasus region. Reasons for the departure from uniformity include a variable noise level (so that more events are detected during quiet times), and failure to eliminate all the blasts. The latter explanation seems more likely as an explanation of the peak in activity shown at 1230 hours GMT, and the similar peak for the top left panel of Figure 3. The peak at around 2000 to 2200 hours GMT is not explained.

RECOMMENDATIONS AND FUTURE PLANS

This project is only 5 weeks old at this time of writing. We expect to acquire further lists of blasting events, and associated information on charge size and signal strength, for different regions including the former Soviet Union, Australia, Canada, China, Korea, and the U.S. We shall document the observability of these events, paying particular attention to any blasts observed teleseismically, and for them we shall compare values of magnitude assigned on different scales.

We also have begun a project to document large single-fired chemical explosions, several of which occurred in the nuclear weapons program of the former Soviet Union. These shots were conducted during 1959 – 1961, in order to gain experience, with chemical explosions, that would assist with the later underground nuclear explosions that began in 1961. These unusual chemical explosions were very similar to the U.S. "chemical kiloton" shot of September 1993.

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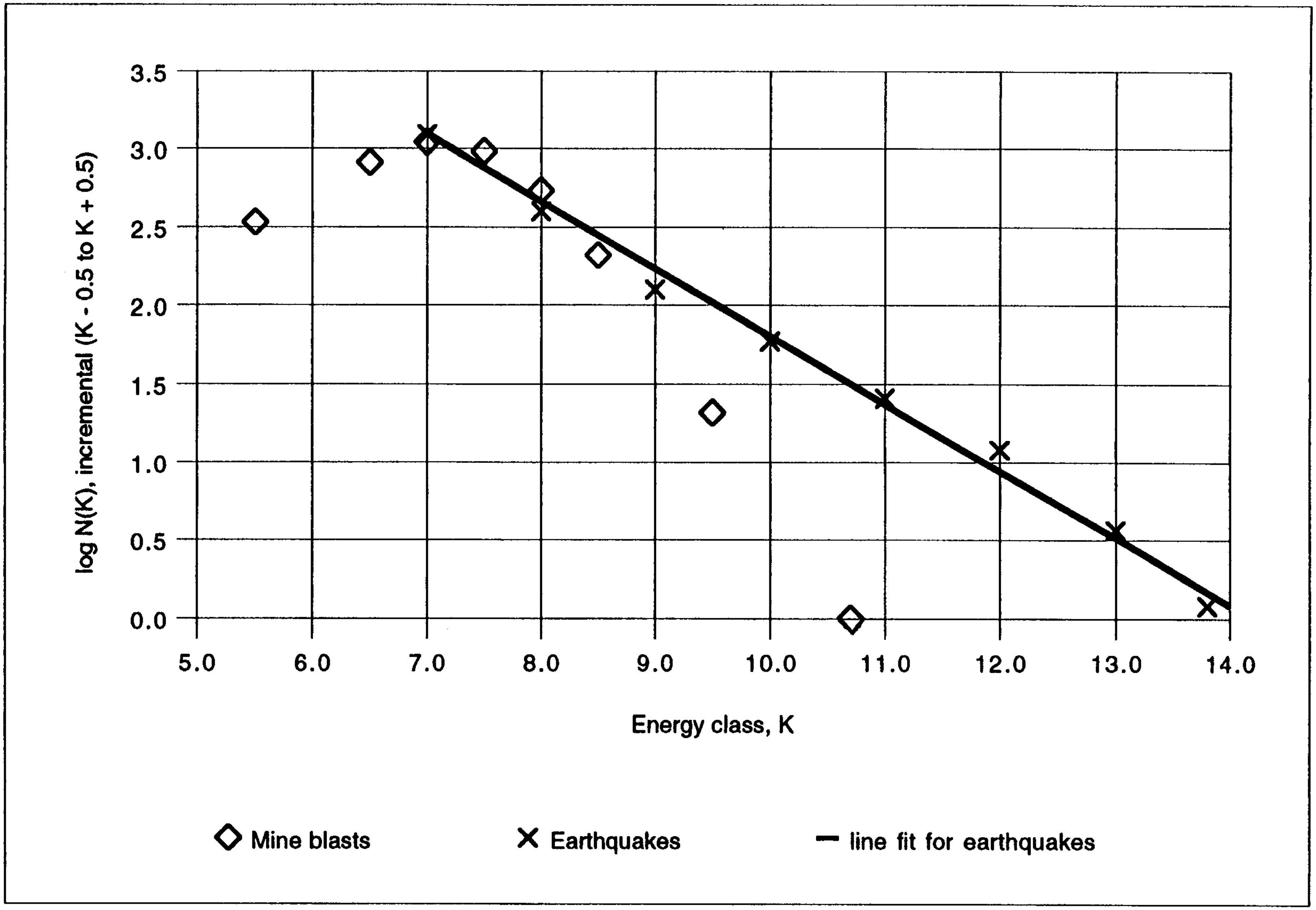

Figure 1. Comparison of recurrence curves for earthquakes and mine blasts in Southeast Kazakhstan (Northern Tien-Shan, 42 – 46° N, 75 – 80° E). The curve for blasts is based upon 5399 such events reported in the bulletin prepared by the Institute for Seismology, Kazakhstan, for the period 1988 – 1994. The slope for earthquakes is 0.43, corresponding to d(log N)/d(mb) = – 1.0, and the bulletin appears to be complete down to K = 7. The slope for mine blasts corresponds to d(log N)/d(mb) = – 2.3. There are very few blasts at the level K = 9 and greater (that is, mb around 3 – 3.5).

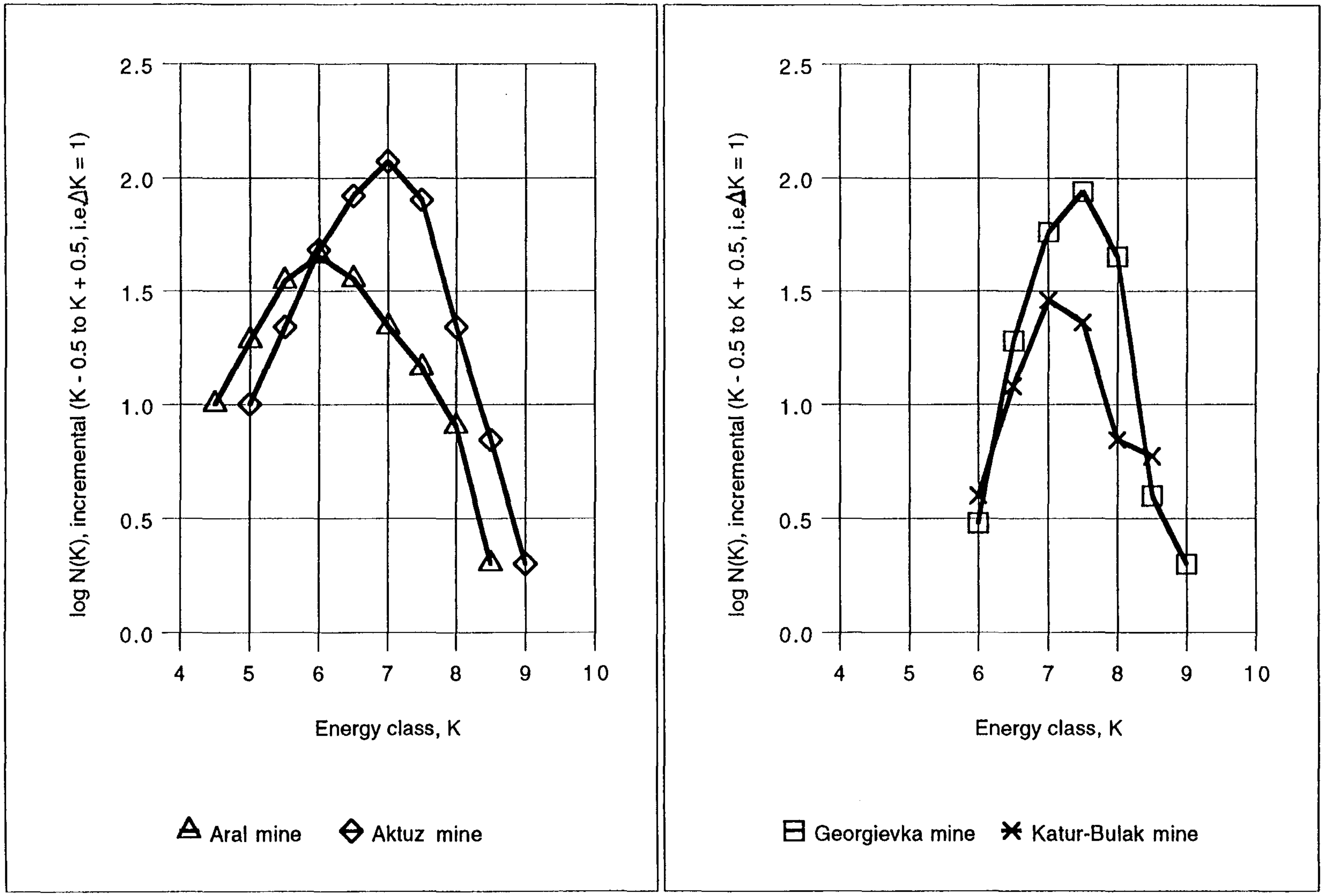

Figure 2. The recurrence curves of blasting signals from four mines in southeastern Kazakhstan during 1988 – 1994, all showing a strong decline in number of blasts with K class increasing above 7; and all showing few if any blasts with K = 9 (corresponding to mb 3 – 3.5).
On the left, are curves for the Aral and Aktuz mines. On the right, are curves for the Georgievka and Katur-Bulak mines.

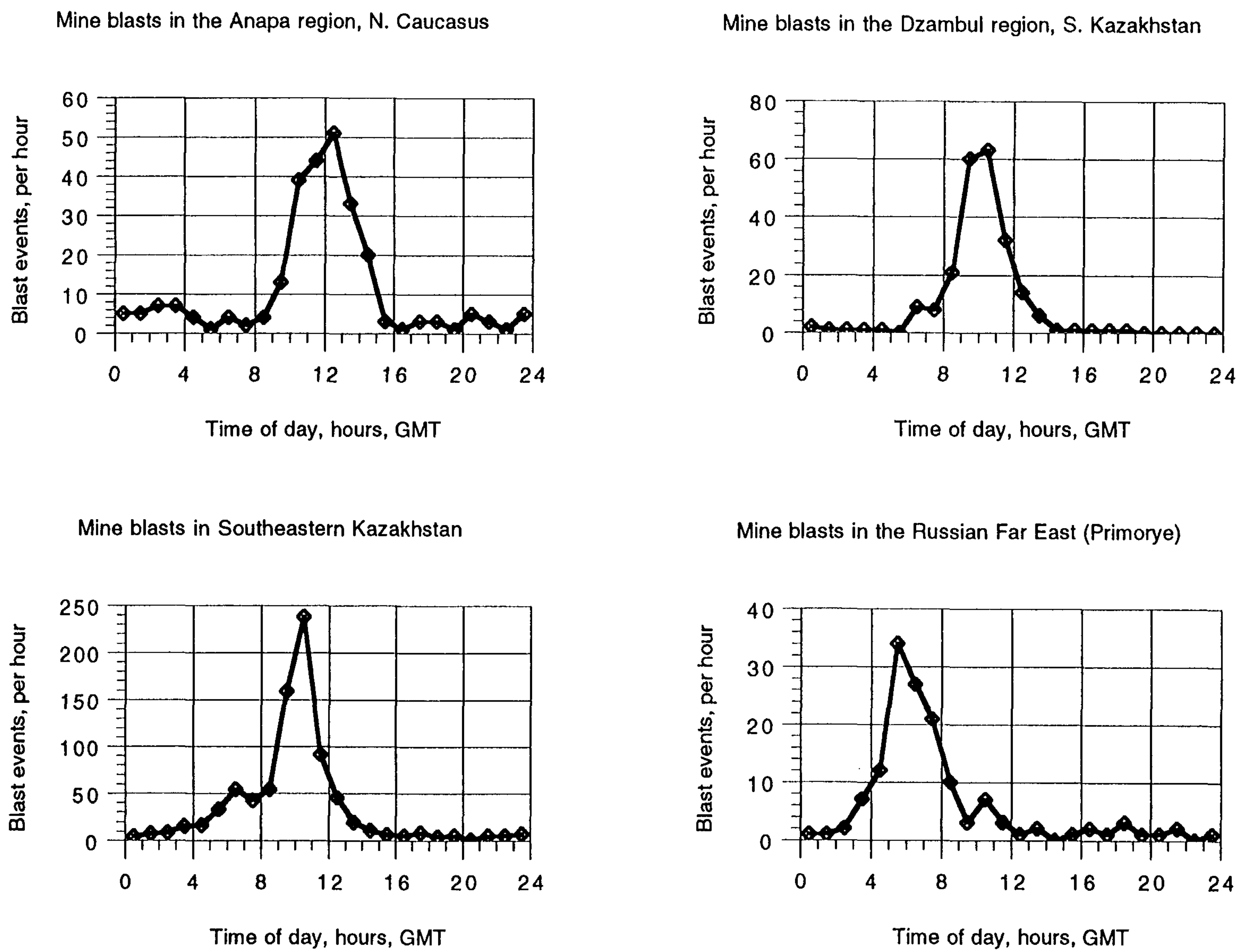

Figure 3. The distribution of mine blasts throughout the day, for four different regions in the former Soviet Union. For the North Caucasus (see top left), the maximum rate occurs at noon GMT, corresponding to 15 – 16 hours local time (the end of the work day). The maximum is shifted with respect to the Caucasus for the two Kazakhstan examples, and for the Russian Far East (see bottom right), but in each case the maximum occurs at a local time corresponding to the end of the work day.

Caucasus catalog, supposedly with blasting removed

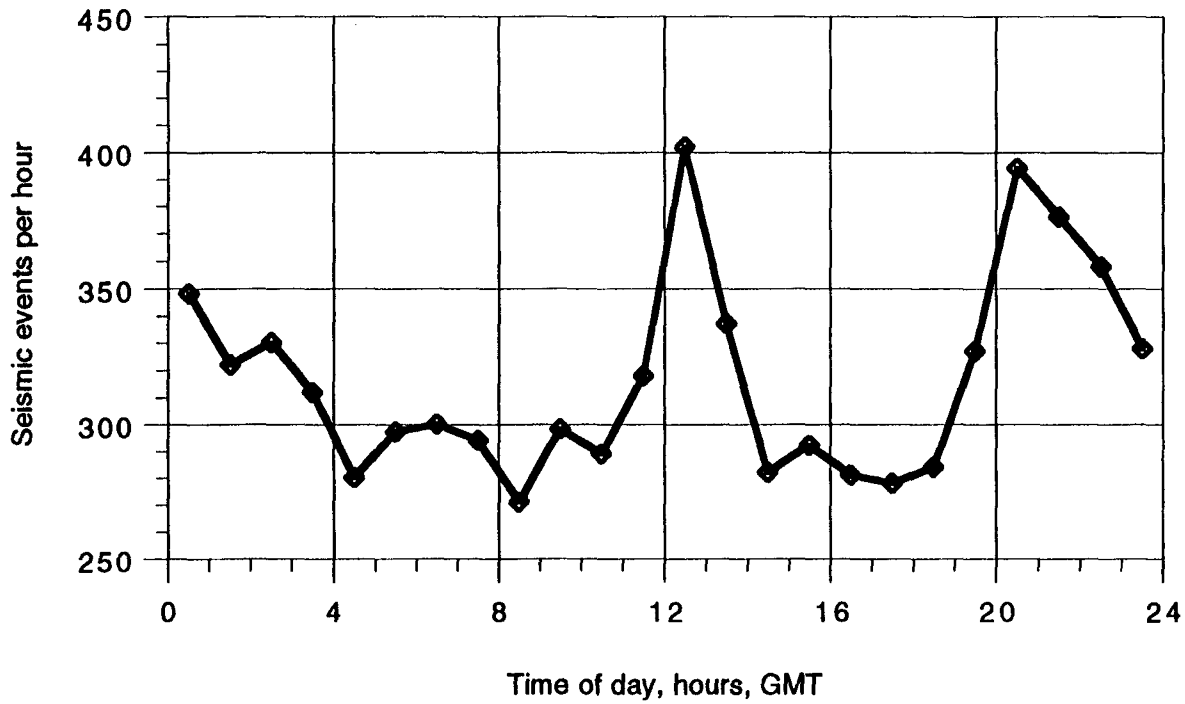

Figure 4. The distribution with respect to time of day (GMT), for events in the official Caucasus catalogue of earthquakes, taken for the years 1962 – 1986 from "Earthquakes in the USSR", published annually by the Institute of Physics of the Earth. From the presence of a strong maximum near 1230 hours, it appears that some blasts remain in this catalogue (compare with Figure 3, top left).